BELLCOMM, INC.

SUBJECT: LEM RCS and Propulsion Thermal Review
Case 330

DATE: March 14, 1966

FROM: T. A. Bottomley, Jr.
S. S. Fineblum

ABSTRACT

A review of the Grumman analysis of the thermal aspects of the LEM RCS, descent propulsion and ascent propulsion systems was attended. The general approach used by Grumman is similar to, and based upon, other widely used computer programs using a system of lumped parameters for a large number of nodes. The predicted temperatures were extreme. Typically, one or more propellant valves are going to get overly hot because of solar or soak-back heat with the consequent danger of evaporating the oxidizer in the valve. At the other extreme, heat loss to space will result in overly cold valves with the danger of either freezing fuel, or oxidizer being too cold to evaporate in the combustion chamber rapidly enough to support smooth combustion. Typically, coated mylar radiation shields and altered heat transfer paths are being proposed as a means of lowering the component temperature.

As a matter of practice, the mass of the LEM is used as a heat sink to cool the critical items. This is justified on the basis of the large mass of propellants and structure that is available to absorb heat with a relatively minor temperature increase. However, the ECS load is thereby increased. Heaters are used to prevent overly cold RCS valves.

These problems which may detract from mission success as well as crew safety have been identified and are being studied. LEM thermal tests within the next six months will be used to verify assumptions and further identify problem areas.

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MEMORANDUM FOR FILE

A meeting was held at MSC, January 5-6, 1966, to review the thermal aspects of the RCS, Ascent Propulsion and Descent Propulsion Systems of the LEM.

R. A. Haslett of Grumman first described the overall network approach to temperature predictions within the LEM. GAEC's main computer program is capable of computing a rather general overall prediction of heat transfer and temperature distribution. This program, the Boeing Beta S, as used by Grumman, is capable of computing approximately 300 nodes. The heat transfer in the immediate neighborhood of the RCS and proppulsion systems is separately evaluated with use of smaller programs which are capable of computing heat transfer between 50 or so nodes. Such programs are written for the particular regions where the preliminary temperature predictions from the general program are either intolerable or marginal. The 35-hour lunar stay is considered to result in an essentially steady-state thermal analysis problem. Thus far, only the steady-state analysis has been performed over the entire LEM. Preliminary runs have been made on the transient problem. The main effort now is to write and check out the transient analysis program.

GAEC RCS Thermal Study

The critical items in the RCS system from the temperature point of view are the oxidizer (N_2O_4) valves which must never see a temperature higher than 175°F. This temperature would cause vapor to form at system pressure. The soak-back condition is most critical. The heat stored within the mass of the hot engine at shut-off is transmitted into the valve which has, then, no mass flow. From present studies, it is believed that the temperature requirements for the oxidizer valve will either be violated or only marginally fulfilled.

In the calculations, the equivalent overall emissivity (ε) of the LEM bay "seen" by the valves on the aft clusters is estimated at approximately 0.6. The TM-2 thermal-vacuum tests will be used to verify this estimate of emissivity.

In solar soak, the aft RCS clusters are critical because the heat transfer path into the nearby heat sink, the LEM equipment bay is longer. Since thermal balance depends on both the heat absorbed and the heat emitted and transmitted to the cooler LEM, this longer heat transfer path results in relatively less thermal energy being transmitted out of the RCS cluster for a given time period. As a result, a quasi-equilibrium condition is achieved at a higher temperature in this aft cluster. If the LEM is 125°F or more and if ε of the equipment bay is 0.6, then the oxidizer valve would probably exceed its maximum permissible temperature of 175°F.

In the shade and during a night lunar stay, the oxidizer valve is the most sensitive to a cold soak. Without a heater and with the LEM as the thermal sink at 70°F, it has been predicted that the coldest valves would drop to approximately 19°F. This is intolerable as the propellants might freeze. In addition, this may be critical for LEM abort because of the delay in bringing the engine components up to 35°F prior to firing. This 35°F limit is based on tests at Marquardt which showed that engine start spikes result with very cold oxidizer valves. The cause of such combustion instability is believed to be the delay in evaporation of overly cold oxidizer and the accumulation of liquid in the engine with retarded but sudden combustion. Approximately 50 watts per quad are available to the RCS heaters, however, to add sufficient heat to the valves. The cold-soak calculations included the conservative assumptions of a lunar night landing with a 50°F LEM cabin temperature and minimum available RCS heater power (i.e., one heater out).

The assumptions for the RCS soak-back predictions which are generally conservative include a sub-solar landing, an 80°F LEM cabin temperature, and maximum equipment usage. In addition, a steady 60-second firing was assumed prior to soak-back. The possibility that a series of repeated RCS runs of shorter duration may be more critical than the assumed steady state 60-second firing is being investigated by GAEC.

For purposes of computing heat transfer during soak-back it was assumed that only one RCS engine was operating and that one-fourth of the total RCS installation mass was assigned to the heat transfer path from that one engine, through the components and into the LEM. This assumption simplifies the calculation while preserving the heat-flux-to-mass ratio which dominates transient heat transfer.

The RCS warning light, which is set to operate at 180°F, suffers the same problem as the CSM RCS units; that is, the sensor is subject to premature activation of the warning light because the surrounding structure in the vicinity of the oxidizer valve is likely to be hotter than the oxidizer valve.

RCS Thermal Testing at GAEC

The thermal testing of an RCS cluster alone is scheduled to begin in May, 1966, at GAEC. The LEM-1, as well as LTA-8, unfortunately includes somewhat inadequate instrumentation (only 22 thermocouples for all four RCS clusters). Eight of the thermocouples are concentrated on the "Y" connections upstream of, rather than on, the oxidizer valves. Grumman is to attempt to relocate these thermocouples on the oxidizer valves themselves, or at least, closer.

MSC requested that Grumman supply the following information as soon as possible:

1. A definition and specification of thermocouples in the RCS warning system.

2. The reliability and logic analysis used for the RCS warning system.

3. A date at which time the cluster alone test can be expected to be completed.

4. A date by which the LEM-1 instrumentation compatibility with the thermal aspects of the mission would be provided.

Descent Engine Thermal Problems

The critical phases are, for analysis, the translunar coast (15-hour roll and 3-hour hold) and, a lunar orbit, (all critically hot) and with the sun along the +x axis prior to a night landing (critically cold). The descent engine, as is the ascent engine, is insulated externally only. Multiple-layer mylar insulation is provided between the descent nozzle and adjacent structure.

The present analysis does not include the heat transfer along the feed lines.

Grumman has recommended a coated mylar plug in the nozzle to occlude radiation between the injector and space. This proposal is being reviewed by TRW at the present time. Without such a shield, it is predicted that the injector would cool to approximately 18°F which is the freezing temperature of the fuel.

The design temperature range for the propellant supply system is between 45°F and 100°F.

Engine firing within 18" or less of the lunar surface is expected to increase the soak-back into the surrounding structure and could create a pressure to the lower structure and base heat shield approximating 3 psi. The combination of increased pressure and temperature is a threat to the adjacent structure, according to GAEC. (A recent Bellcomm study* does not confirm this conclusion.) The present analysis by Grumman assumes that the bottom of the LEM base heat shield would be at least 6 inches from the lunar surface.

The uncontrolled venting of overheated propellants is a problem because of the possible exposure of the crew operating outside the LEM to such vented propellants. This problem is under study.

The design temperature of the titanium tank is now approximately 100°F. The design temperature of the gimbal ring, which may become critical, is approximately 300°F.

The worst case for the single supercritical helium tank which is now most critical, is in the barbecue mode. The heat leak into this helium tank is predicted to be approximately 7.5 BTU's per hour. The aliminum bracket supporting the helium tank has been replaced by titanium bracket and it is expected that this will greatly reduce the heat short.

Ascent Engine Thermal Problems

The oxidizer valve has a maximum permissible temperature of approximately 220°F for the purposes of obtaining a minimum closing time. It was determined that, as the oxidizer valve temperature increases, the performance of the oxidizer valve solenoid deteriorates such that the closing time is intolerably extended. This is serious because it prevents the pulse firing of the engine within the required design limits.

The engine outer case temperature limit is 500°F to insure engine restart. The engine cover inside the cabin should

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*Memorandum for File, "LEM Descent Engine Plume Impingement Study with Jettisonable Nozzle Skirt," December 30, 1965, R. Sehgal.

be no higher than 200° for crew protection. It is planned to reject heat through the engine cover and into the cabin with the understood ECS penalty.

It is predicted that a cabin temperature may reach approximately 120° for a depressurized cabin under sub-solar conditions. MSC representative expressed concern about the loss of proper radiation characteristics during fire "in the hole" which may cause damaged paint.

Bell is concerned about overheating the ascent injector. The maximum temperature of 130°F is the design criteria for all the ascent propulsion plumbing behind the insulation. The oxidizer temperature limit of 120°F is determined by the danger of boil-off which would result in fuel lead and a hard start. GAEC has predicted approximately 300° in the valve at the injector and in oxidizer lines. This is definitely excessive for the valve (220°F maximum) and the oxidizer lined (190°F maximum). GAEC has proposed that a shield be placed around the oxidizer valve to avoid the presently predicted excessive temperature.

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